Chapter I. Introduction

Introduction

This report presents an analysis of the affects of physical processes on the potential for riparian habitat on the San Joaquin River from Friant Dam to the confluence of the Merced River. Natural physical processes affecting the river and riparian vegetation include surface and groundwater hydrology, bank and bed erosion and deposition, channel and floodplain hydraulics and sediment transport, and other channel-forming influences. The timing, pattern, and magnitude of these natural physical processes have been altered by local and state flood control projects, operation of reservoir dams and weirs, reclamation of the river floodplain and basin lands for agricultural and urban uses, and mining of sand and gravel from channel deposits. Progressive changes in fluvial processes and channel and floodplain topography since the late 19th century have altered the physical habitat for riparian vegetation along the river, modifying its distribution, pattern, and potential for regeneration. Biological factors, such as the introduction of large herbivores and invasive trees and shrubs, have further contributed to vegetation response.

Study Purpose and Objectives

This study is sponsored and supervised by the San Joaquin River Riparian Habitat Restoration Program (SJRRHRP). The SJRRHRP is a collaborative effort of the Friant Water Users Authority (FWUA), Natural Resource Defense Council (NRDC), Pacific Coast Federation of Fishermen's Associations (PCFFA), U.S. Bureau of Reclamation (USBR), and U.S. Fish and Wildlife Service (USFWS), with participation by other local and state agencies, special districts, conservation groups, and private landowners. The purpose of the SJRRHRP is to plan and implement improvements to environmental conditions along the San Joaquin River, with a special emphasis on mutually acceptable riparian habitat restoration projects and management prescriptions. The study objectives include describing and analyzing the physical processes affecting the San Joaquin River in the study area, determining how physical processes affect the distribution of riparian vegetation, understanding how riparian vegetation is constrained by physical conditions and current river management, and recommending feasible approaches to the future expansion or enhancement of riparian habitat. An additional, related objective is to further interpret the results of the SJRRHRP-sponsored mapping of the historical and existing extent of riparian habitat along the San Joaquin River in the same study area. A companion report, *Historical Riparian Habitat Conditions of the San Joaquin River*, accompanied by color geographic information system (GIS) maps and charts was issued in April 1998 (Jones & Stokes Associates 1998).

The analysis presented in this report was prepared jointly by Jones & Stokes Associates and Mussetter Engineers Inc., under the direction of the SJRRHRP management team. In addition, Ayres Associates conducted river cross section surveys and associated stage-discharge curves, and John Cain provided historical data and maps and contributed to the development of concepts for potential riparian restoration projects.

Study Area and Important River Subreaches

The study area (Figure 1.1 and map in Appendix A consists of nearly 150 miles of the mainstem of the San Joaquin River between Friant Dam at Millerton Reservoir (River Mile [RM] 267.5) and the confluence of the Merced River at Hills Ferry (RM 118). However, the interpretation of fluvial processes affecting the mainstem river requires a broader understanding of a larger geographic context. Geographic features of primary influence include the San Joaquin River flood control and bypass system (Chowchilla, Eastside, and Mariposa Bypasses and associated weirs) and the natural flood basins and sloughs (e.g., Mariposa, Mud, and Salt Sloughs) that historically received out-of-bank flows exceeding the natural capacity of the San Joaquin River channel. The flood basin bordering the San Joaquin River is criss-crossed by numerous named and unnamed sloughs (anabranching channels), all of which collectively reconverge flood flow back into the mainstem river where the alluvial fan of the Merced River constricts the valley floor.

The mainstem river has been divided into five primary reaches and the reaches subdivided into subreaches (Figure 1.1 and map in Appendix A); the reaches and subreaches correspond to major transitions in the geomorphology (the shape of the channel and its floodplain) and hydrology of the river. The subreaches are listed in Table 1.1. (The reach and subreach designations are the same as those used in *Historical Riparian Habitat Conditions of the San Joaquin River*.) Important facilities and features along the river are listed in Table 1.2, along with the River Mile (RM) locations. River Mile 0 is at the confluence with the Sacramento River in the Sacramento–San Joaquin River Delta (Delta) at Antioch.

Related Studies In Progress

At least two concurrent studies are being conducted to evaluate geomorphic conditions on the San Joaquin River, potential floodplain restoration, and riparian ecology.

The first of these studies, the Sacramento and San Joaquin River Basins Comprehensive Study, is being sponsored jointly by the U.S. Army Corps of Engineers, Sacramento District (Sacramento District), the California Department of Water Resources, and the Reclamation Board of the State of California. The comprehensive study is being conducted in response to team reports prepared by the Interagency Task Force and the Governor of California's Flood Emergency Action Team (FEAT) in the aftermath of the January 1997 floods, which emphasized the need for long-term comprehensive flood control planning for the Central Valley. The comprehensive study is intended to identify management options for reducing flood damages while restoring environmental values in the floodplains of the Sacramento and San Joaquin River systems. The Congressional legislation funding the study calls for:

- a comprehensive post-flood assessment,
- development of hydrologic and hydraulic models of the river systems for planning purposes, and
- formulation of a comprehensive plan for flood control and environmental restoration.

The primary focus of the comprehensive study is the floodplains, flood control levee and bypass systems, and major regulating reservoirs within the Sacramento and San Joaquin River basins. Both nonstructural and structural approaches are under consideration. Nonstructural approaches include establishment of meanderbelt agreements, creation of levee setbacks, development of new overflow basins, acquisition of floodway easements, relocation of flood-prone structures, and modification of reservoir operations. Structural approaches may include modifying or creating new bypass systems, creating new upstream storage, and modifying bypass system flows to restore habitat values.

The second concurrent study is being conducted by the U.S. Fish and Wildlife Service (USFWS). The USFWS San Luis Refuge was awarded two competitive CALFED grants in 1997: one to acquire refuge land for conservation purposes ($15 million) and the other to conduct an evaluation and develop a hydraulic model of conceptual alternatives for restoring westside floodplains of the San Joaquin River in the vicinity of Bear Creek. USFWS initiated the study in August 1998. The evaluation will include potential benefits of floodplain storage and attenuation of flood peaks along the San Joaquin River; effects on area levees, roads, bridges, and culverts; and ecological effects of restored seasonal inundation of historical floodplains on refuge lands. Floodplain inundation may require a formal deauthorization of 10 to 20 miles of state funded levees along the refuge portion of the river.

Background on the San Joaquin River

Climate and Surface Hydrology

The annual precipitation in the basin ranges from about 6 inches on the valley floor at Mendota to about 70 inches at the headwaters of the San Joaquin River in the Sierra Nevada (U.S. Army Corps of Engineers 1993). Precipitation in the valley occurs primarily from November to April; very little occurs during the summer months. The basins on the west side of the valley that drain the Coastal Ranges lie in a rain shadow and receive less precipitation than those on the east side of the valley that drain the Sierra Nevada. Snowpack accumulates on the east side of the basin above an elevation of about 5,000 feet, and the snowmelt generally begins to runoff by April.

Two types of floods occur in the basin, those that result from intense rainfall during the late fall and winter and those that result from snowmelt during the spring and summer. The highest peak discharges occur from floods driven by rainfall runoff, but the durations of flooding from these events tend to be lower. Regional flood frequency curves (Pitlick 1988) indicate that for rainfall-on-snow types of flood events in the central Sierra Nevada region, the magnitude of the 100-year event exceeds that of the mean annual flood by a factor of about 5. In contrast, the 100-year snowmelt flood exceeds the mean annual flood by a factor of about 1.5. The largest flood from rainfall recorded at the Friant gage was 77,200 cfs in December 1937. Since then, the largest has been the 1997 flood, which had an estimated peak discharge of about 60,000 cfs. The highest rainfall flood at the Newman gage was 36,900 cfs in March 1986. In contrast, the highest snowmelt flood at the same gage was 19,300 cfs in June 1968 (U.S. Army Corps of Engineers 1993). Cain (1997), using simulated unimpaired flows at the Friant gage from 1908 to 1997, demonstrated that the largest floods (rainfall-on-snow) historically occurred in the upper reaches of the San Joaquin River basin between November and January. Before the development of the flood control and water storage projects in the basin, floodwaters were reported to stand in the lateral flood basins along the river for 3 –5 months per year (Hall 1887).

Reservoirs within the basin have significantly affected the flood hydrology in the basin. The peak discharge of the 2-year event (highest flow occurring on average every two years) has been reduced by about 25%, and the 10-year flood peak has been reduced by about 41% (Bay Institute 1997). Cain (1997), however, argued that although the water development projects have significantly affected the magnitude of the higher-frequency floods, they have not affected the magnitudes of the less frequent events. In other words, the magnitude of the 200-year flood before and after the construction of water development projects is similar (96,250 cfs). A more in-depth discussion of flood frequency and duration is provided in Chapter 3.

There are no instream minimum flow requirements downstream of Friant Dam. However, the USBR releases between 35 and 230 cfs to support riparian water rights between the dam and Gravelly Ford. In the irrigation season, the USBR is required to provide releases of about 5 cfs past the Gravelly Ford gage site (Cain 1997). As a result of the lack of in-stream minimum flows, the channel of the San Joaquin River is essentially dry from Gravelly Ford to the Mendota Pool, except under flood release conditions. Delta-Mendota Canal water is conveyed in the San Joaquin River between Mendota and Sack Dam, but the channel again becomes dry downstream until agricultural tailwater and seepage from canals creates a base flow. Return flows in Salt and Mud Sloughs contribute to the low-flow discharges in the lower part of the river as does some groundwater return.

Major Tributaries

The vast majority of the basin runoff occurs from the eastside tributaries to the San Joaquin River, and very little is contributed by the westside tributaries (Corps 1993). Several small tributaries enter the San Joaquin River between Friant Dam and Gravelly Ford, the largest of which is Little Dry Creek, which is also used to convey excess floodwater from the Big Dry Creek flood control project located northeast of Fresno (Corps 1993). Between Gravelly Ford and the Merced River, floodflows enter the San Joaquin River flood control system from the Fresno and Chowchilla Rivers; the Fresno, Ash, and Berenda Sloughs; and Bear Creek and several other small streams via the Eastside and Chowchilla Bypasses. Dams are located on all of the eastside tributaries. During periods of high runoff in the Kings River basin to the south, water is discharged to the San Joaquin River from the Tulare Basin via Fresno Slough and the James Bypass. Historically, groundwater from Tulare Lake discharged into the San Joaquin River via Fresno Slough, and a 19th century account speculated that the groundwater inflow from the Tulare Basin increased the summer low flows downstream of Mendota by as much as 33% (Anonymous 1873).

Geology, Geomorphology, and Soils

The San Joaquin River basin is an asymmetrical basin, the axis of which is offset to the west. The basin lies between the crests of the Sierra Nevada and Coast Ranges and extends from the northern boundary of the Tulare Lake basin (Kings River alluvial fan) to the southern boundary of the Delta near Stockton. The basin is about 100 miles wide and 120 miles long. At Friant, the upstream drainage area totals about 1,638 square miles; at Dos Palos, it is about 5,630 square miles; and at Fremont Ford (on Highway 140), it is about 7,615 square miles. Elevations in the basin range from sea level at Stockton to about 13,000 feet in the Sierra Nevada. Within the study area, elevations range from about 70 feet at Hills Ferry to about 300 feet near Fresno. The average slope of the San Joaquin River within the study reach is about 0.0003 (1.6 feet per mile [ft/mi]).

The San Joaquin River basin lies within parts of the Sierra Nevada, California Coast Ranges, and Great Central Valley geomorphic provinces. The Sierra Nevada is composed primarily of crystalline igneous rocks (granite, quartz monzonite, quartz diorite) with some metamorphic rocks (Western Metamorphic Belt) and volcanic and meta-volcanic rocks. The Coast Ranges consist of folded and faulted Jurassic and Cretaceous-age sedimentary rocks. The valley floor is underlain by relatively unconsolidated upper Tertiary-age and Quaternary-age sediments that are water bearing and are confined by the impermeable middle to late Pleistocene-age Corcoran clay (Norris and Webb 1976). The Great Valley trough is interrupted by two major surface cross structures, the Stockton Fault in the Stockton Arch and the White Wolf Fault in the south near Bakersfield. The geologic evidence indicates that the valley has been undergoing almost continuous deformation since the Mesozoic (Davis and Green 1962, Bull and Miller 1975). Geologically driven subsidence of the valley is ongoing and is on the order of 0.25 millimeters per year (mm/yr) (Janda 1965, Ouchi 1983). Groundwater withdrawal and hydrocompaction of the soils by irrigation have led to accelerated subsidence since the 1920s (Poland et al. 1975, Bull 1964). Maximum amounts of subsidence (about 30 feet since the 1920s) have occurred in the Los Banos–Kettleman City area, but from 1 to 6 feet of subsidence have occurred along portions of the San Joaquin River between Mendota and about Los Banos, a rate of about 35 to 43 mm/year (Ouchi 1983).

The east side of the valley is composed of a series of coalesced alluvial fans that have formed at the margin between the Sierra Nevada and the valley. The alluvial fans of the larger rivers—the Kings, San Joaquin, and Merced—have prograded out into the basin and have formed major geomorphic subunits along the valley. Each of the fans forms a local base level control (i.e., a rise or fixed elevation at a point in the channel thalweg to which the river gradient must adjust) and has significantly affected the distribution of historical flood flows by creating backwater conditions. (Hall 1887). Base level for the study reach is the Merced River alluvial fan. Downstream of Friant Dam, the river flows over a series of granitic, metamorphic and volcanic (pumice) outcrops that control local base level and limit sand and gravel mining–induced degradation (Cain 1997). From Friant Dam downstream to near Gravelly Ford, the San Joaquin River is deeply incised below Pleistocene-age terraces that are composed of paleo-alluvial fan sediments (Janda 1965).

Soils in the valley bottom are poorly drained and fine textured and may be saline. Bordering, and just above, the basin bottoms are soils of the fans and floodplains, which are generally deep, well drained, and fertile. Caliche layers (cemented hardpans) are present within the soils of the distal fan margins. The soils of the terraces that border the outer edges of the valley are of poorer quality and have dense clay subsoils or hardpans at shallow depths (U.S. Army Corps of Engineers 1993). Irrigation drainage (tailwater), especially in the lower portion of the study area, including Mud and Salt Sloughs, has been shown to contain high levels of salts, pesticides, and heavy metals. Since the cessation of discharge of tailwater to Kesterton National Wildlife Refuge, the discharge of agricultural tailwater to the San Joaquin River has doubled; it now comprises about 12% of the flow in the river (Bay Institute 1997). Salts and heavy metal loadings have increased significantly as a result (Saiki et al. 1993).

Riparian Vegetation

The existing and historical distribution and extent of riparian vegetation and associated riverine cover types, as well as agricultural crops and other land uses, are mapped and described in *Historical Riparian Habitat Conditions of the San Joaquin River* (Jones & Stokes Associates 1998). For each of the five major reaches, the report provides tables and graphs showing the acreage of cover types for each of the four major epochs mapped (photo years 1937, 1957, 1978, and 1993), and representative cross sections for 1938 and 1993. This report does not duplicate the maps, tables, and descriptive narrative provided in the historical riparian study report. However, the results contained in that report are considered in this study as part of the current and historical baseline conditions of channel planform, adjacent land use, and vegetation pattern.

Appendix B contains aerial and ground level color photographs of the river and environs. Plates 46 through 86 focus on views of riparian vegetation conditions, structure, pattern, and apparent limiting factors. Table 5.1 summarizes generalized patterns and apparent trends of riparian habitat in each study reach along the San Joaquin River.

Land Use Along the River

Dominant land use types bordering or occurring within the river channel and active floodplain include agriculture and range land, sand and gravel mining, urban and recreational uses, waterfowl management areas, and flood control facilities and infrastructure. Table 1.3 summarizes the dominant riverside land uses by river subreach.

Dams and Reservoirs

Development of water resources in the San Joaquin River basin began over 130 years ago. Each of the main tributaries to the San Joaquin River, as well as the river itself, has a dam and reservoir that includes storage space for flood control. Pine Flat Dam on the Kings River, completed by the Corps in 1954, has a storage capacity of 1 million acre-feet, of which 260,000 acre-feet are reserved for flood storage. Except in unusual circumstances, the reservoir has eliminated historical overflows into the San Joaquin River via the Kings River North and Fresno Slough.

Since 1911, nine reservoirs with a combined storage capacity of 1.14 million acre-feet (about 60% of the watershed yield) have been built upstream of the town of Friant on the San Joaquin River and its upper tributaries (Cain 1997). Friant Dam, which forms Millerton Lake, was constructed by USBR in 1941. The lake has about 530,000 acre-feet of storage, of which about 170,000 acre-feet can be reserved for flood control. In contrast to most dams, which attenuate flood peaks but then release the stored water downstream, most of the storage in Millerton Lake is distributed via the Madera Canal (to the north) and Friant-Kern Canal (to the south); these canals were completed in 1943 and 1948, respectively.

Mendota Dam, located at the confluence of the San Joaquin River and Kings River North (Fresno Slough), was constructed in 1954 and is used for irrigation water supply diversion. The dam provides no flood control storage and has, in fact, become filled with sediment (U.S. Army Corps of Engineers 1993), thereby affecting upstream water-surface elevations during flood flows in the San Joaquin and Kings River North. Delta-Mendota Canal water is conveyed to Mendota Dam in exchange for Friant-Kern-Madera flows and is then distributed downstream via a network of canals—Columbia, Helm, Outside, Main, Poso and Arroyo—and the San Joaquin River as far as Sack Dam, a low-head structure with no storage capacity at about River Mile 182.

The eastside tributaries are also dammed. Hidden Dam, located on the Fresno River, was completed by the Corps in 1974. Hensley Lake, formed by the dam, has a capacity of 90,000 acre-feet, of which 65,000 acre-feet are reserved for flood storage. Buchanan Dam, which forms H.V. Eastman Lake, is located on the Chowchilla River. The lake has a capacity of 150,000 acre-feet, of which 45,000 acre-feet are reserved for flood storage. Smaller structures with a combined flood storage capacity of about 33,300 acre-feet are located on Bear Creek (Burns Dam, Bear Dam), Owens Creek (Owens Dam), and Mariposa Creek (Mariposa Dam). Big Dry Creek Dam is located on Big Dry Creek northeast of Fresno. New Exchequer Dam and Lake McClure are located about 25 miles northeast of Merced on the Merced River. Although the Merced River forms the downstream boundary for this study, the 1 million acre-feet of storage in McClure Lake, of which about 350,000 acre-feet are available for flood storage, has had a significant effect on the hydrologic record at the Newman gage, which is just downstream of the Merced confluence at RM 118.

Flood Control Projects

Local levees and flood control projects were commenced between about 1915 and 1930 by local landowners. From about 1956 to 1972, the Corps constructed the Lower San Joaquin River and Tributaries project from the Delta upstream to the Merced River, under the authorization of the 1944 Flood Control Act. Under the same authorization, the State of California constructed the Eastside Bypass project from the Merced River upstream to the head of the Chowchilla Bypass between 1959 and 1966. The bypass system and its associated levees isolated about 240,000 acres of floodplain from the river (U.S. Army Corps of Engineers 1985). The bypass system consists primarily of man-made channels (Chowchilla, Eastside, and Mariposa Bypasses) that divert and carry floodflows from the San Joaquin River near Gravelly Ford, along with flows from the eastside tributaries, downstream to the mainstem San Joaquin River upstream of the Merced River confluence (Figure 1.2). The system consists of about 193 miles of levees, several control structures (Chowchilla Canal Bypass Structure, San Joaquin River Control Structure, Sand Slough Control Structure, Eastside Bypass Control Structure, Mariposa Bypass Structure) and other associated facilities (Mariposa Bypass Drop Structure, Ash Slough Drop Structure).

The system was designed to provide a 50-year level of flood protection (Hill pers. comm.). Operation and maintenance of the State upstream bypass system and its associated levees and control structures is the responsibility of the Lower San Joaquin Levee District (LSJLD). Non-project local levees parallel the river between Mendota and just upstream of the Mariposa Bypass, at approximately RM 151. The head of the levees on the San Joaquin River are at RM 225 (left bank) and RM 227 (right bank), approximately 4 and 2 miles downstream of Gravelly Ford (RM 229), respectively. Between 1968 and 1970, the Corps conducted channel clearing and snagging work from Gravelly Ford to Highway 145 (RM 234) under Section 208 of the 1954 Flood Control Act.

Design capacities for the individual elements of the flood control system are shown on the map in Appendix A and in Table 1.4. The operational criteria at the Chowchilla Bypass Control Structure for the project design discharge of 8,000 cfs, the first bifurcation in the system, is to pass the first 2,500 cfs down the San Joaquin River to Mendota Pool. The next 5,500 cfs is diverted into the Chowchilla Bypass. When total flows exceed 8,000 cfs, efforts are made to force the flow into the bypass (Landis pers. comm.).

The design capacity between Mendota (RM 205) and the Sand Slough Control Structure (RM 168) is 4,500 cfs. Based on the system design at the Sand Slough Control Structure, 3,000 cfs is forced into the Eastside Bypass, and 1,500 cfs is passed down the San Joaquin River. However, it is doubtful whether the San Joaquin channel has the capacity to convey 1,500 cfs; in practice, only 300–400 cfs is released into the channel (Hill pers. comm.). At the Mariposa Bypass Control Structure, the first 8,000 cfs is routed back to the San Joaquin River to help local drainage of the eastside tributaries by keeping the stage as low as possible in the Eastside Bypass. The design capacity for the San Joaquin River mainstem between the Mariposa Bypass (RM 147) and the Bear Creek confluence (confluence with Eastside Bypass) at RM 136 is about 10,000 cfs. From the Bear Creek confluence to the Merced River confluence at RM 118.5, the design capacity for the mainstem San

Joaquin River is 26,000 cfs. Table 1.2 provides the location of important features within the study area.

The LSJLD has channel maintenance responsibilities for the San Joaquin River between Gravelly Ford and the Merced River. However, the U.S. Fish and Wildlife Service has discouraged channel maintenance work (vegetation and sediment removal) on federal land within the boundaries of the San Luis National Wildlife Refuge. The channel of the San Joaquin River downstream of the Sand Slough Control Structure is also constricted by vegetation growing within the channel, which is assumed to reduce the flow capacity of this subreach. The difficulty in obtaining permits for mechanical or chemical vegetation removal and the high cost removing vegetation by hand to maintain channel capacity may be affecting the design flow capacities in the system (Hill pers. comm.).

By 1985, levee subsidence and sediment accumulation had reduced the capacity of the lower 1.5 to 2 miles of the Eastside Bypass to about 6,000 to 7,000 cfs from the design capacity of about 16,500 cfs. To correct the capacity problem, the Corps removed about 1 million cubic yards of deposited sand and the LSJLD raised the levee height (U.S. Army Corps of Engineers 1993). The Eastside Bypass levees were originally constructed with 4 feet of freeboard, except for the west side levee, which had 3 feet of freeboard.   Sediment removal from within the bypasses downstream of the Sand Slough and Chowchilla Control Structures is primarily undertaken by local contractors on an as-needed basis. The system flow capacity has been significantly reduced as a result of subsidence in the Eastside Bypass, vegetation growth within the channel of the San Joaquin River, and sediment accumulation as a result of bank erosion within the river and the bypasses. (Hill pers. comm.).

The State of California has a designated floodway program that is administered by the Reclamation Board. The designated floodway provides a nonstructural means of reducing potential flood damages by preventing encroachments into flood-prone areas. Designated floodways are located along the Kings River North and between Friant Dam and Gravelly Ford (RM 267-229) and Salt Slough and the Merced River (RM 168–118.5). The Federal Emergency Management Agency (FEMA) 100-year floodplain from the head of the Chowchilla Bypass (RM 216) to the Merced River (RM118.5) is shown on Figure 1.3 (U.S. Army Corps of Engineers 1993). FEMA has also mapped the 100-year floodplain in the vicinity of Fresno below Friant Dam.

Prior Investigations and Studies

This investigation of the physical processes and dynamics of the San Joaquin River through time has depended heavily on a rather extensive body of existing work. Historical maps of the system provide a baseline for the system prior to significant human-caused interventions (Hall 1887, The Bay Institute 1998). The

California Debris Commission's (CDC) topographic survey of the San Joaquin River in 1914 (U.S. Army Corps of Engineers 1917) has provided a baseline set of morphometric data (i.e., measures of channel geometry) that represents conditions in the San Joaquin River and the marginal flood basins and floodplains prior to the onset of major human-caused interventions. Sample portions of these historical maps are provided in Appendix D. Fourteen cross sections that span the survey limits between the Merced River and Herndon (RM 243) (see map in Appendix A for locations) were digitized and have been reproduced in Appendix C. However, the CDC survey does indicate that some development had already taken place. Local levees were in place and a number of drains and canals had been constructed. Time sequential aerial photography from 1937, 1957, 1978, and 1993 has provided an analysis of historical changes in the extent and spatial distribution of riparian habitat and adjacent land use (Jones & Stokes Associates 1998). Sources of aerial photography for the analysis of historical changes in the riparian habitat are provided in the report.

Existing conditions in the San Joaquin River basin were thoroughly summarized by the Corps Reconnaissance Report for the San Joaquin River Mainstem (U.S. Army Corps of Engineers 1993). Of particular value are the detailed descriptions of the flood control project and project hydrology (design discharges) for individual elements of the project upstream of the Merced River confluence. Similarly, The Bay Institute (1998) has thoroughly summarized the ecological changes that have attended the physical transformation of the San Joaquin River since the early part of the 20th century.

Cain (1997) conducted an in-depth evaluation of hydrologic and geomorphic changes to the San Joaquin River from Friant Dam to Gravelly Ford. Specifically, he quantified changes in flow durations, magnitudes, and frequencies as a result of upstream flow storage and regulation and related these changes to morphological changes in the river caused by interruptions in the sediment transport regime. The study shows that upstream trapping of sediment and in-channel and channel margin sand and gravel extraction between Friant and Gravelly Ford have caused significant channel degradation. Cain's work is heavily relied upon in this investigation of the physical processes and dynamics of the San Joaquin River.

A number of one-dimensional hydraulic models (HEC-2 or HEC-RAS) were available to evaluate channel capacity and flooding limits for specific reaches of the San Joaquin River in the study reach. Specifically, these include the Department of Water Resources (DWR) Bear Creek model (RM 136-152), Borcalli and Associates' Firebaugh model (RM 191-198), Highway 99 model (RM 243-244), and the Fresno Metropolitan Flood Control District (FMFCD) model (RM 245-270). Because these models were developed to assess flooding limits, they have limited value for assessing hydraulic conditions for a range of lower flows without major modifications, which was beyond the scope of this study. When possible, the existing models were used to evaluate channel capacities and stage-discharge relations.

Time sequential survey information was acquired from the California Department of Transportation for bridges that cross the San Joaquin River and the Eastside Bypass to determine whether there were aggradational or degradational changes in the system (i.e., deposition or erosion of the channel bed, causing an overall raising or lowering of thalweg elevation. [The thalweg is the bottom of the channel]). Comparison of CDC 1914 cross sections with 1978 resurveyed profiles at the same sixteen locations between Vernalis and the Merced River by the U.S. Geological Survey (USGS) indicated that there had been from 2 to 9 feet of channel incision (Simpson and Blodgett 1979). Bridge survey data were obtained for the following bridges: Highway 140 (San Joaquin River), Highway 165 (San Joaquin River), Highway 152 (San Joaquin River), Highway 152 (Eastside Bypass), Ness Avenue (Eastside Bypass), Highway 145 (San Joaquin River), Highway 99 (San Joaquin River), and Highway 41 (San Joaquin River).